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| Application Number | : | 200200437-2 |
| Applicant(s) / Proprietor(s) of Patent | : | NANYANG TECHNOLOGICAL UNIVERSITY |
| Title of Invention | : | STEERING OF DIRECTIONAL SOUND BEAMS |

Chan

SERENE CHAN (Ms)
Assistant Registrar
*for* REGISTRAR OF PATENTS
SINGAPORE

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Rule 19

*SINGAPORE*
*PATENTS ACT*
*(CHAPTER 221)*
*PATENTS RULES*

25 JAN 2002

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*The Registrar of Patents*
*Registry of Patents*

***REQUEST FOR THE GRANT OF A PATENT***
*THE GRANT OF A PATENT IS REQUESTED BY THE UNDERSIGNED ON THE BASIS OF THE PRESENT APPLICATION*

| | | |
|---|---|---|
| *I. Title of Invention* | Steering of Directional Sound Beams | |
| *II. Applicant(s)* (*See note 2*) | *(a) Name* | Nanyang Technological University |
| | *Body Description/ Residency* | A body corporate incorporated under the Nanyang Technological University Act (cap. 162) |
| | *Street Name & Number* | c/o Innovation and Technology Transfer Office, Blk 1, Unit 213, 16 Nanyang Drive |
| | *City* | Singapore |
| | *State* | Singapore |
| | *Country* | Singapore 637722 |
| | *(b) Name* | |
| | *Body Description/ Residency* | |
| | *Street Name & Number* | |
| | *City* | |
| | *State* | |
| | *Country* | |
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| | *City* | |
| | *State* | |
| | *Country* | |

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| *III. Declaration of Priority (see note 3)* | *Country/Country Designated* | | *File no.* | |
| | *Filing Date* | | | |
| | *Country/Country Designated* | | *File no.* | |
| | *Filing Date* | | | |
| | *Country/Country Designated* | | *File no.* | |
| | *Filing Date* | | | |

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| *IV. Inventors (See note 4)*<br>*(a) The applicant(s) is/are the sole/joint inventor(s).*<br>*(b) A statement on Patents Form 8 is/will be furnished.* | [ ] *Yes*<br>[X] *Yes* | | [X] *No*<br>[ ] *No* | |
| *V. Name of Agent (if any) (See note 5)* | Sachithananthan Suresan | | | |
| *VI. Address for Service (See note 6)* | *Block/Hse No* | 9 | *Level No* | |
| | *Unit No/PO Box* | #15-00 | *Postal Code* | 049910 |
| | *Street Name* | Battery Road | | |
| | *Building Name* | Straits Trading Building | | |
| *VII. Claiming an earlier filing date under section 20(3), 26(6) or 47(4). (See note 7)* | *Application No* | | | |
| | *Filing Date* | | | |
| | [Please tick in the relevant space provided]:<br><br>( ) Proceeding under rule 27(1)(*a*).<br>Date on which the earlier application was amended = ________<br>or<br>( ) Proceeding under rule 27(1)(*b*). | | | |

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|---|---|
| *VIII. Invention has been displayed at an International Exhibition (See note 8)* | ☐ *Yes* ☒ *No* |
| *IX. Section 114 requirements (See note 9)* | The invention relates to and/or used a micro-organism deposited for the purposes of disclosure in accordance with section 114 with a depository authority under the Budapest Treaty. ☐ *Yes* ☒ *No* |

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|---|---|---|---|
| *X. Check List* (To be filled in by applicant or agent) | *A. The application contains the following number of sheet(s):-* | | |
| | *1. Request* | 4 | *sheets* |
| | *2. Description* | 13 | *sheets* |
| | *3. Claim(s).* | 4 | *sheets* |
| | *4. Drawing(s).* | 9 | *sheets* |
| | *5. Abstract.* | 1 | *sheets* |
| | *B. The application as filed is accompanied by:-* | | |
| | *1. Priority document* | | |
| | *2. Translation of priority document* | | |
| | *3. Statement of Inventorship & right to grant* | | |
| | *4. International Exhibition Certificate* | | |

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|---|---|---|
| *XI. Signature(s) (See note 10)* | *Applicant (a)* | |
| | *Date* | 25 January 2002 |
| | *Applicant (b)* | |
| | *Date* | |
| | *Applicant (c)* | |
| | *Date* | |

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NOTES:

1. This form when completed, should be brought or sent to the Registry of Patents together with the prescribed fee and 3 copies of the description of the invention, and of any drawings.

2. Enter the name and address of each applicant in the spaces provided at paragraph II. Names of individuals should be indicated in full and the surname or family name should be underlined. The names of all partners in a firm must be given in full. The place of residence of each individual should also be furnished in the space provided. Bodies corporate should be designated by their corporate name and country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided. Where more than 3 applicants are to be named, the names and address of the fourth and any further applicants should be given on a separate sheet attached to this form together with the signature of each of these further applicants.

3. The declaration of priority at paragraph III should state the date of the previous filing, the country in which it was made, and indicate the file number, if available. Where the application relied upon in an International Application or a regional patent application e.g. European patent application, one of the countries designated in that application [being one falling under the Patents (Convention Countries) Order] should be identified and the name of that country should be entered in the space provided.

4. Where the applicant or applicants is/are the sole inventor or the joint inventors, paragraph IV should be completed by marking the 'YES' Box in the declaration (a) and the 'NO' Box in the alternative statement (b). Where this is not the case, the 'NO' Box in declaration (a) should be marked and a statement will be required to be filed on Patents Form 8.

5. If the applicant has appointed an agent to act on his behalf, the agent's name should be indicated in the spaces available at paragraph V.

6. An address for service in Singapore to which all documents may be sent must be stated at paragraph VI. It is recommended that a telephone number be provided if an agent is not appointed.

7. When an application is made by virtue of section 20(3), 26(6) or 47(4), the appropriate section should be identified at paragraph VII and the number of the earlier application or any patent granted thereon identified. Applicants proceeding under section 26(6) should identify which provision in rule 27 they are proceeding under. If the applicants are proceeding under rule 27(1)(*a*), they should also indicate the date on which the earlier application was amended.

8. Where the applicant wishes an earlier disclosure of the invention by him at an International Exhibition to be disregarded in accordance with section 14(4)(c), then the 'YES' Box at paragraph VIII should be marked. Otherwise the 'NO' Box should be marked.

9. Where in disclosing the invention the application refers to one or more micro-organisms deposited with a depository authority under the Budapest Treaty, then the 'YES' Box at paragraph IX should be marked. Otherwise the 'NO' Box should be marked.

10. Attention is drawn to rules 90 and 105 of the Patent Rules. Where there are more than 3 applicants, see also Note 2 above.

11. Applicants resident in Singapore are reminded that if the Registry of Patents considers that an application contains information the publication of which might be prejudicial to the defence of Singapore or the safety of the public, it may prohibit or restrict its publication or communication. Any person resident in Singapore and wishing to apply for patent protection in other countries must first obtain permission from the Singapore Registry of Patents unless they have already applied for a patent for the same invention in Singapore. In the latter case, no application should be made overseas until at least 2 months after the application has been filed in Singapore.

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# STEERING OF DIRECTIONAL SOUND BEAMS

## FIELD OF THE INVENTION

The present invention relates to the field of ultrasonics and nonlinear acoustics for generating hyper-directional audible sound beams. In particular the invention relates to a method and apparatus for steering the hyper-directional sound beams to a desired location and to systems incorporating such method and apparatus.

## BACKGROUND OF THE INVENTION

An audio system for generating hyper-directional sound beams in the audible range is known. The audio system employs a parametric array of acoustic transducers to project through the air ultrasonic carrier signals modulated with signals representing audible sounds. Due to non-linearity of air when excited by finite amplitude ultrasonic waves, the audible sounds self demodulate on passage through the air, creating new sounds or *virtual sources* along a selected projection path to produce a hyper-directional sound beam in the audible range. Although the sound beam is demodulated with relatively high levels of harmonic and intermodulation distortions it is possible to obtain a relatively linearized characteristic by pre-distorting or pre-conditioning the audible signal before modulation.

The sound beams produced by the above technique may be focused, steered or projected in a defined area or direction.

One useful application for the sound beams is in advertising. A problem with simultaneous audio-broadcasting of advertising material is that it creates noise pollution in public places such as shopping malls, public transport stations (bus stops and train terminals), conference and exhibition halls and the like. This may create a relatively high level of interference and confusion for the listener who hears mixed signals from different broadcasting sources.

A parametric audio system incorporating a steering function that uses a phased array technique is described in WO01/52437 (Frank Joseph Pompei). The latter system includes a delay circuit to apply a relative phase shift or delay across all frequencies of the modulated carrier signal to steer, focus, or shape ultrasonic beams generated by the acoustic transducer array but may not steer the audible sound beam to the desired path exactly.

**SUMMARY OF THE INVENTION**

The present invention may address this problem by creating a private listening space for passers-by, passengers, shoppers and visitors without contributing significantly to noise pollution of the environment. At the same instant, a more coherent and intelligible message may reach the listener without experiencing too much distortion and noise interference. A variation of the present invention may provide a directional audio directory which can act as a guide for directing passers-by to their destinations. The present invention may allow conventional billboards each incorporating a sound beam to be placed relatively close to one another and still be able to maintain their respective private listening spaces without mutual interference.

The sound beam may be steered by mechanical means such as a stepper motor which may be arranged to rotate the array of transducers to cover an immediate area in front of a billboard panel, for example. An alternative may make use of digital beamforming techniques to perform a similar function.

The array of transducers may directly project at the listener or alternatively may project at a surface which serves to reflect the directional sound to the listener. The latter may create an audible image of the sound source and the impression on the listener that the sound is transmitted directly from the surface.

An extension to the present invention may include a video camera to provide an image of a potential listener. An intelligent tracking system may

detect the location of the listener and may steer the sound beam directly to the listener to allow a message to follow a moving listener.

The present invention may create a private listening space around the listener without disturbing his neighbours. The system of the present invention may accept an audio signal from any one of a plurality of sources including a CD player, FM radio receiver or digital broadcast radio receiver and transmit it within the area of the private listening space.

The present invention is based on the recognition that it is the audible sound beam which is to be steered to the desired area, so the phased array technique used in the prior art cannot be applied to the modulated carrier signal since ultrasonic delays will be inherited by the resultant virtual sources. The presence of the ultrasonic delays in the audible sound beam may then lead to unexpected interference during interaction among virtual sources. The present invention attempts to address this in one form by applying suitable delays to both the modulating signal in the audible range and the carrier signal in the ultrasonic range.

Moreover, if traditional lead zirconate titanate (PZT) transducers are adopted, each device may have a slightly different peak frequency or there may be a slightly different phase corresponding to each resonant frequency. To ensure uniform transducers, matching filters may be introduced, e.g. by electrically controlling delay to each transducer.

The present invention may provide a beamforming technique which may suitably adjust not only the phases of the primary waves, notably both the modulating signal in the audible range and the carrier signal in the ultrasonic range as discussed previously, but may also adjust the amplitudes or weights of the transducer elements in the parametric array to steer the sound beam. Such weight adjustments can be used to minimize spreading of the sound beam over large distances by the use of a Bessel distribution source. The latter may be constructed by weighting the arrangement of transducers by a Bessel function to produce a non-diffracting beam. The transducers may be driven with

amplitudes which are adjusted to produce a zeroth order Bessel function. In theory such a beam travels to infinity without spreading. This may reduce the requirement of power and ensure high directivity along a desired path over a large distance. The transducers may be arranged in an annular or substantially annular array.

Use of an ultrasonic wave having a pressure profile that approximates a zeroth order Bessel function to minimize diffraction of the wave is described in US Patent Specification 5,081,995 (Mayo foundation for Medical Education and Research). The theory for designing non-diffracting ultrasound beam is given by J. Durnin in an article "Exact solutions for nondiffracting beams. I. The scalar theory." published in the *Journal of Optical Society of America* 4(4): 651-654, 1987. This solution indicates that transducers can be constructed which produce a wave that is confined to a beam that does not diffract, or spread, over a long distance. The disclosures of the two latter documents are incorporated herein by cross reference.

According to one aspect of the present invention there is provided an apparatus for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said apparatus including:

means for generating an audio signal;

means for generating an ultrasound carrier signal;

means for modulating said carrier signal with said audio signal;

means for adjusting the amplitude and phase of at least one of said audio signal and said carrier signal to steer said audio beam to a desired direction; and

means for generating an ultrasound beam in said direction driven by said modulated carrier signal.

According to a further aspect of the present invention there is provided an apparatus for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said apparatus including:

means for generating an audio signal;

means for generating an ultrasound carrier signal;

means for modulating said carrier signal with said audio signal;

means for generating an ultrasound beam driven by said modulated carrier signal; and

means for adjusting said means for generating to steer said audio beam to a desired location.

According to a still further aspect of the present invention there is provided a method of steering a directional audio beam that is self-demodulated from an ultrasound carrier, said method including the steps of:

generating an audio signal;

generating an ultrasound carrier signal;

modulating said carrier signal with said audio signal;

adjusting the amplitude and phase of at least one of said audio signal and said carrier signal to steer said audio beam to a desired direction; and

generating an ultrasound beam in said direction driven by said modulated carrier signal.

According to a still further aspect of the present invention there is provided a method for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said method including the steps of:

generating an audio signal;

generating an ultrasound carrier signal;

modulating said carrier signal with said audio signal;

generating an ultrasound beam driven by said modulated carrier signal; and

adjusting said means for generating to steer said audio beam to a desired direction.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Preferred embodiments of the present invention will now be described with reference to the accompanying drawings wherein:-

Fig. 1 shows an audio billboard that beams directional audio advertising to passers by;

Fig. 2 shows one arrangement of audio transducers associated with a billboard;

Fig. 3 shows an alternative arrangement of audio transducers associated with a billboard;

Fig. 4 shows a block diagram of control and processing apparatus associated with an audio billboard according to the present invention;

Fig. 5 shows a prior art phased array technique;

Fig. 6 shows a block diagram of an ultrasound modulator incorporating beam steering according to the present invention;

Fig. 7 shows the beamsteering process when only delays and gains in the audible range are applied to the modulating signal;

Fig. 8 shows the beamsteering process when only delays and gains in the ultrasonic range are applied to the carrier signal;

Fig. 9 shows the beamsteering process when suitable delays and gains in both the audible and ultrasonic ranges are applied respectively to the modulating and carrier signals; and

Fig. 10 shows a graphical representation of the profile of a zeroth order Bessel function and an associated ultrasound pressure profile produced by an ultrasonic transducer.

## DETAILED DESCRIPTION

Fig. 1 shows billboard panel 10 which incorporates a system for generating a hyper-directional audible sound beam 11 according to the present invention. The billboard encompasses an implementation and integration of an array of ultrasonic transducers which generates the directional sound beam in association with a conventional billboard panel. The system may include a digital signal processing module that processes an audio signal from a sound source and sends it to a modulating and amplifying circuit. This in turn drives a group of ultrasonic transducers in the array, (also known a parametric acoustic array) and transmits a modulated ultrasonic beam. At high sound pressure levels, self-demodulation occurs due to nonlinear interaction in air and causes

secondary audible frequencies to appear within the beam. Such a phenomenon of creating new sounds or *virtual sources* along a selected projection path (such that they reinforce one another) enables a hyper-directional sound beam to be produced in the audible range. These newly produced secondary waves in the air retain the narrow beam characteristics of the primary counterpart and are useful in creating a private listening or advertising space around the listener. Sound sources into the signal processing module may be provided from a CD player, FM radio receiver or a digital broadcast radio receiver.

Fig. 2 shows an arrangement for steering the sound beam 20 to a specified area or location. The arrangement may include a stepper motor (not shown) for rotating an array of ultrasonic transducers 21 at least relative to vertical axis 22. The stepper motor may be installed at the base of array 21 to enable array 21 to be rotated to allow beam 20 to cover an immediate area in front of billboard panel 10 to reach listener A, B or C selectively. The beam 20 may produce a private advertising space in the vicinity of the selected listener which does not intrude on adjacent spaces. A digital beam steering device as described below may be used in place of the stepper motor to perform a similar function.

An alternative placement for ultrasonic transducer array 21 is in a housing directly behind the billboard panel 10. Panel 10 may include a graphic poster made of permeable fabric or other suitable or porous medium. The audio beam propagating out of the array may penetrate through the porous medium without significant signal attenuation and there is less space consumption since transducer array 21 is concealed behind the poster inside the housing of panel 10.

A further extension may include a video camera to provide an image of the potential listener. An intelligent tracking system may detect the location of the listener and may steer the audio beam directly to the listener to allow a message to follow a moving listener or passenger. The array of transducers can be arranged in a convex shape to widen the arc of the beam.

Fig. 3 shows an arrangement similar to Fig. 2 in which the sound beam 20 is reflected from the surface of billboard panel 10 to reach a listener as a reflected beam 20' to produce the impression of a sound source emanating from the surface of billboard panel 10.

The apparatus shown in Fig. 4 includes preprocessor module 40 for processing an audio signal from a sound source such as a CD player, FM radio or digital broadcast radio receiver. In preprocessor module 40, a DC offset is first applied to the audio signal in such a way as to enhance the audio quality of the resultant demodulated signal. The preprocessor may include means to predistort or precondition the signal in order to obtain a relatively linearized characteristic after self demodulation of the audio signal. One form ~~or~~ of preprocessing is discussed in a paper entitled Parametric Array in Air: Distortion Reduction by Preprocessing by Thomas D. Kite, et al., ICA/ASA Proceedings, Seattle WA June 1998. Another form of preprocessing or equalization is discussed in a paper entitled The audio spotlight: An application of nonlinear interaction of sound waves to a new type of loudspeaker design by Masahide Yoneyama et al. J. Acoustical Society of America Vol. 73 No. 5 May 1983. The disclosures of the two later documents are incorporated herein by cross reference.

The output from preprocessor module 40 is sent to beam steering and modulator unit 41. Beam steering and modulator unit 41 will accept a control signal from beam steering controller 42 and performs gain and delay adjustment for beamforming (non-diffraction Bessel-type) and beamsteering. In addition, beam steering and modulator unit 41 receives ultrasound carrier 43 and modulates the signal from preprocessor module 40 to an ultrasonic signal and sends it to driver 44 via filter module 45. The modulated ultrasonic signal is amplified via driver 44 sufficiently to drive an array of ultrasonic transducers 46 (also known as a parametric acoustic array) to produce a finite-amplitude (high pressure level) modulated ultrasonic beam.

Because practical transducers have slightly different peak frequencies which limit their arrayability, a corresponding set of matching filters is included in filter

module 45 for aligning the transducers. The matching filters in module 45 individually control the delay to each transducer to adjust the phase of the driving signal to the resonant frequency of the associated transducer. Phase alignment of array 46 provides a more effective radiation pattern that is not distorted as a result of variations in transducer response characteristics.

To steer the beam to a specified area or direction, stepper motor 47 is installed at the base of the ultrasonic transducer array 46 to enable the device to be rotated and to cover the immediate area in front of a billboard panel. A digital beam steering controller 42 as described herein may also be incorporated into the ultrasonic transducer array to perform a similar function or to extend the range of steering of the beam. The transducer array 46 can be used to directly project at the listener or to project at a surface which serves to reflect the directional sound to the listener as described with reference to Fig.3. The latter may create an image of the sound source and the impression on the listener that the same sound is transmitted directly from the surface.

Video camera 48 may provide an image of a target zone in the vicinity of a billboard in which potential listeners or the sound beams may move. Image processing and control unit 49 may include an image recognition capability to detect moving listeners in the target zone and to control stepper motor 47 and/or beam steering controller unit 41 to steer ultrasonic transducer array 46 towards and with the moving listeners.

In Fig. 4, there are several means of controlling the direction of the beam, which make use of beam steering controller unit 41 and/or stepper motor 47. For example, if stepper motor 47 only is used, it may rotate ultrasonic transducer array 46 to the desired direction (i.e. beam steering controller 42 is not used to control the direction of the beam). Alternatively, beam steering controller 42 may be used in place of stepper motor 47 (i.e. stepper motor 47 is not used to control the direction of the beam). Finally, beam steering controller 42 and stepper motor 47 may be used in combination. This may provide a wider range of directions and a more flexible manner of controlling the beam.

Fig. 5 shows a prior art beam forming arrangement for steering a sound beam using a phased array technique. A delay circuit in the prior art arrangement applies a relative phase shift across all frequencies of the modulated carrier signal to steer, focus or shape ultrasonic beams generated by the transducer elements. However, as noted above employing a phased array technique to a modulated carrier signal may not achieve the desired steering because the self-demodulated audio signal inherits the ultrasonic delays of the modulated carrier. The presence of ultrasonic delays in the audible sound beam may then lead to unexpected interference during the acoustic interaction within the audible sound beam. As a result the audible sound beam may not be steered to the desired path.

In one form the present invention attempts to address this problem by applying suitable delays to both the modulating signal in the audible range and the carrier signal in the ultrasonic range. With such a configuration which is more general and flexible for various uses, the audible beam may be steered to the desired path more exactly. Moreover, with the adjustment of the gains at locations identical to that of the said delays, a non-diffracting beam based on a zeroth-order Bessel function may also be realised.

Fig. 6 shows a block diagram of a beam steering arrangement according to the present invention. The beam steering arrangement includes beam steering unit 41 receiving a pre-processed audio signal from preprocessor module 40. Preprocessor module 40 applies a pre-distorting or equalizing function to the audio signal as described above to obtain a relatively linearized characteristic for the demodulated sound beam. Beam steering unit 41 includes gain and phase adjustment modules 61, 62 for adjusting the amplitude and phase of the pre-conditioned audio signal and ultrasound carrier 43 respectively. Beam steering controller 42 is used to deliver gain and phase information to beam steering unit 41. The modulated carrier signal is applied to driver 44 which drives ultrasonic transducer array 46 as described with reference to Fig. 4.

Figs 7-9, show various illustrations of the beamsteering process. In each case, the appearance of virtual sources along the propagation path (up to the

point where the propagating wave ceases to be finite-amplitude) is the result of the self-demodulation process. In Fig 7, a vector only of phases or delays in the audible range is applied to the modulating audio signal before the amplitude modulation. No delays are applied to the carrier signal. In this way, the ultrasonic beam may be projected straight in front of the parametric array without any steering. However as a result of the self-demodulation process, the reproduced audible signal in air may retain its phased response along the wavefronts of the virtual sources, arising in an audible range *secondary beamsteering* phenomenon in the vicinity where virtual sources are formed.

In Fig 8, a vector only of phases or delays in the ultrasonic range is applied to the carrier signal before the amplitude modulation. No delays are applied to the modulating audio signal. In this way, the ultrasonic beam may be steered directly in front of the parametric array. Similarly due to the self-demodulation process, the reproduced audible sound beam in air may follow the direction of the ultrasonic beam which is perpendicular to the wavefronts of the virtual sources. In this case, there is no *secondary beamsteering*.

In Fig 9, vectors of phases or delays in both the audible and ultrasonic ranges are applied to the modulating and carrier signals respectively before the amplitude modulation. The ultrasonic beam may be steered directly in front of the parametric array. The wavefronts of the virtual sources produced may now be perpendicular to the direction of the steered ultrasonic beam. The reproduced audible sound beam in air however experiences *secondary beamsteering* and may steer yet a second time off the axis of the steered ultrasonic beam. Such a configuration is flexible for implementing a larger steering angle for the audible sound beam as constraint previously was in the narrowness of the beam pattern of each transducer element.

To obtain a substantially diffraction-free radiation pattern the array is weighted by a Bessel function to construct a Bessel distribution source (see Fig. 10). The Bessel function is implemented via either or both Bessel beam generators included in modules 61 and 62 that receive a suitable vector of gains and delays from beam steering controller 42. The bessel beam generators

include a plurality of adjustable gains, each of which corresponds to a respective transducer element. While the delays are applied in the said methods to steer the audible sound beam, the gains are adapted to synthesize a zeroth order Bessel function along a desired steering path or direction. In the preferred embodiment, an exact solution of the wave equation for free space,

$$(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2})\psi(\vec{r},t) = 0 \qquad (1)$$

is given by

$$\psi(\vec{r},t) = e^{-j\omega t}\int_0^{2\pi} \exp\{i\alpha[x\cos(\phi) + y\sin(\phi)] + i\beta z\}d\phi \qquad (2)$$

where $\nabla^2 = \partial^2/\partial r^2 + (1/r)\partial/\partial r$ is the Laplacian operator, $\phi$ is the polar angle, $\vec{r}$ represents the observing point, $t$ is time, $\omega$ is angular frequency of the sound, and $c$ is the speed of sound. Denoting $\theta$ to be the angle that wave vector makes with the $z$ axis, gives

$$\alpha = k\cos(\theta) \qquad (3)$$

and

$$\beta = k\sin(\theta) \qquad (4)$$

Physically, the integral in Eq. (2) represents plane waves propagating at a fixed angle $\theta$ with respect to the $z$ axis for all $2\pi$ polar angles, and can be shown to be proportional to the zeroth-order Bessel function, $J_0$, giving a field $\psi(\vec{r},t)$ of

$$\psi(\vec{r},t) = e^{i(\beta z-\omega t)} \cdot J_0(\alpha r) \qquad (5)$$

when $0 < \alpha \leq k$, this beam being non-diffracting.

The array of transducers may be arranged in an annular array to facilitate synthesis of a zeroth order Bessel beam. As illustrated in Fig. 10, the radius of each annulus may be chosen to be the $J_0$ zeros, so that each annulus spans a single lobe and the gains of each transducer is determined to be the maximum amplitude of the $J_0$ lobe that it spans. In theory such a beam travels to infinity without spreading.

Directional sound beams produced according to the present invention have applications in many products that may benefit from steering sound eg. to alarm

a person or animal in a defined area, to transmit audible sound over a long distance with high levels of directivity for military or sports applications, to provide a dynamic (scanning) reproduction system for sound effects and the like etc.

Finally, it is to be understood that various alterations, modifications and/or additions may be introduced into the constructions and arrangements of parts previously described without departing from the spirit or ambit of the invention.

## CLAIMS

1. Apparatus for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said apparatus including:

means for generating an audio signal;

means for generating an ultrasound carrier signal;

means for modulating said carrier signal with said audio signal;

means for adjusting the amplitude and phase of at least one of said audio signal and said carrier signal to steer said audio beam to a desired direction; and

means for generating an ultrasound beam in said direction driven by said modulated carrier signal.

2. Apparatus according to claim 1 including means for weighting said audio and/or carrier signal by a zeroth order Bessel function to synthesize a Bessel distribution source.

3. Apparatus according to claim 2 wherein said means for generating an ultrasound beam includes a plurality of ultrasound transducer elements and said means for weighting includes a plurality of adjustable gain and delay elements, each gain and delay element corresponding to a respective transducer element.

4. Apparatus according to claim 1 or 2 wherein said means for generating an ultrasound beam includes a plurality of ultrasound transducer elements and a corresponding plurality of matching filters adapted to adjust the phase of the modulated carrier signal to the resonant frequency of the associated transducer element.

5. Apparatus according to any one of the preceding claims wherein said means for generating an audio signal includes at least one of a CD player, FM radio receiver and digital broadcast radio receiver.

6. Apparatus according to any one of the preceding claims including means for preprocessing said audio signal to reduce distortion of said self-demodulated audio beam.

7. Apparatus according to any one of the preceding claims wherein said means for generating an ultrasound beam includes a plurality of ultrasound transducer elements arranged in an annular or substantially annular array.

8. Apparatus for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said apparatus including:

means for generating an audio signal;

means for generating an ultrasound carrier signal;

means for modulating said carrier signal with said audio signal;

means for generating an ultrasound beam driven by said modulated carrier signal; and

means for adjusting said means for generating to steer said audio beam to a desired location.

9. Apparatus according to claim 8 wherein said means for generating includes a plurality of transducer elements and said means for adjusting includes a stepper motor for rotating said transducer elements relative to at least one axis.

10. Apparatus according to claim 8 or 9 including a video camera for providing an image of a potential listener, means for detecting the location of the listener from said image and means to control said means for adjusting to steer said means for generating towards said location.

11. Apparatus according to any one of the preceding claims wherein said audio beam is reflected from an intermediate surface such as a billboard panel.

12. A method of steering a directional audio beam that is self-demodulated from an ultrasound carrier, said method including the steps of:

generating an audio signal;

generating an ultrasound carrier signal;

modulating said carrier signal with said audio signal;

adjusting the amplitude and phase of at least one of said audio signal and said carrier signal to steer said audio beam to a desired direction; and

generating an ultrasound beam in said direction driven by said modulated carrier signal.

13. Method according to claim 12 including weighting said audio and/or carrier signal by a zeroth order Bessel function to synthesize a Bessel distribution source.

14. Method according to claim 13 wherein said step of generating an ultrasound beam includes driving a plurality of ultrasound transducer elements with said modulated carrier signal and said step of weighting includes adjusting gain and delay of said audio and/or carrier signal prior to driving each transducer element.

15. Method according to claim 1 or 2 wherein said step of generating an ultrasound beam includes driving a plurality of ultrasound transducer elements via a corresponding plurality of matching filters adapted to adjust the phase of the modulated carrier signal to the resonant frequency of the associated transducer element.

16. Method according to any one of claims 12 to 15 wherein said step of generating an audio signal is performed by means of at least one of a CD player, FM radio receiver and digital broadcast radio receiver.

17. Method according to any one of claim 12 to 16 including preprocessing said audio signal to reduce distortion of said self-demodulated audio beam.

18. Method according to any one of claims 12 to 17 wherein said step of generating an ultrasound beam is performed by means of a plurality of ultrasound transducer elements arranged in an annular of substantially annular array.

19. Method for steering a directional audio beam that is self-demodulated from an ultrasound carrier, said method including the steps of:

generating an audio signal;

generating an ultrasound carrier signal;

modulating said carrier signal with said audio signal;

generating an ultrasound beam driven by said modulated carrier signal; and

adjusting said means for generating to steer said audio beam to a desired direction.

20. Method according to claim 19 wherein said step of generating is performed by means of a plurality of transducer elements and said step of adjusting is performed by means of a stepper motor for rotating said transducer elements relative to at least one axis.

21. Method according to claim 19 or 20 including detecting the location of a potential listener and adjusting said means for generating to steer said audio beam towards said location.

22. Method according to any one of claims 12 to 21 including reflecting said audio beam from an intermediate surface such as a billboard panel.

23. Apparatus for steering a directional audio beam substantially as herein described with reference to Figs. 2 to 4 and 6 to 10 of the accompanying drawings.

24. A method for steering a directional audio beam substantially as herein described with reference to Figs. 2 to 4 and 6 to 10 of the accompanying drawings.

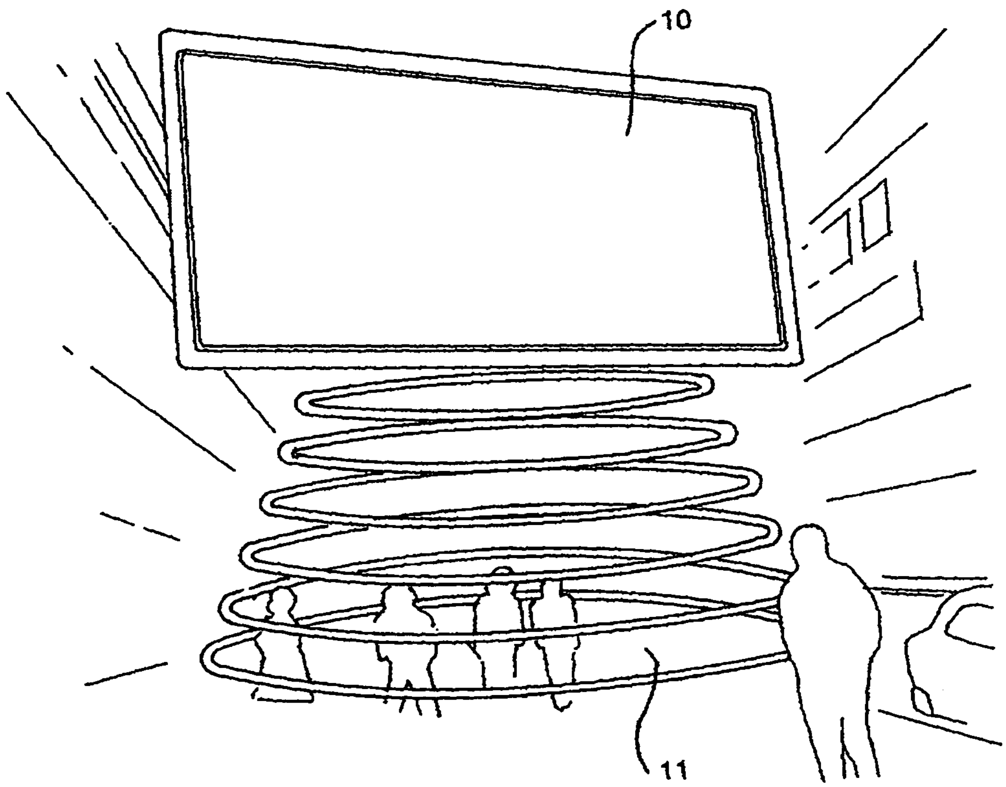



FIG 1

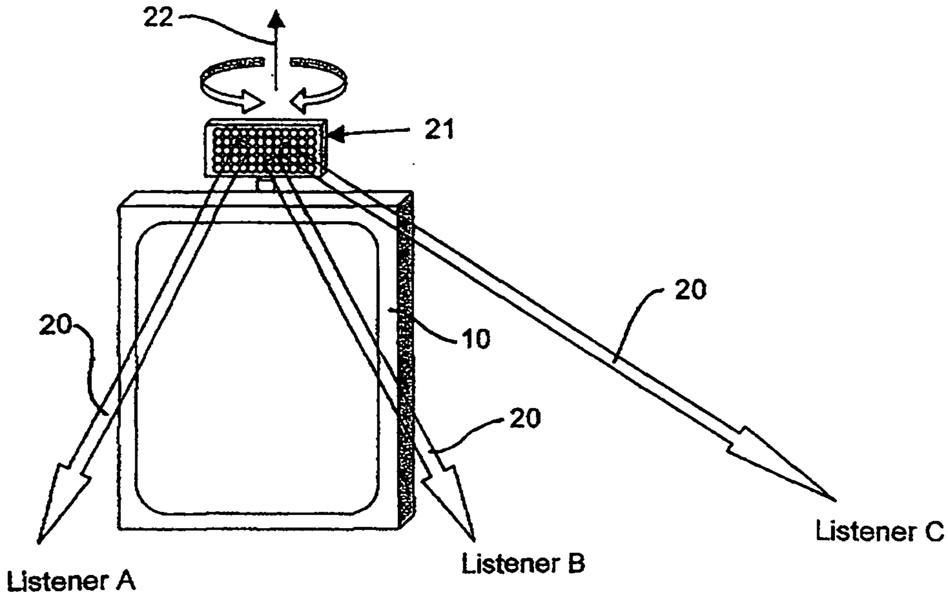

22
21
20
10
20
20
Listener A
Listener B
Listener C

FIG 2

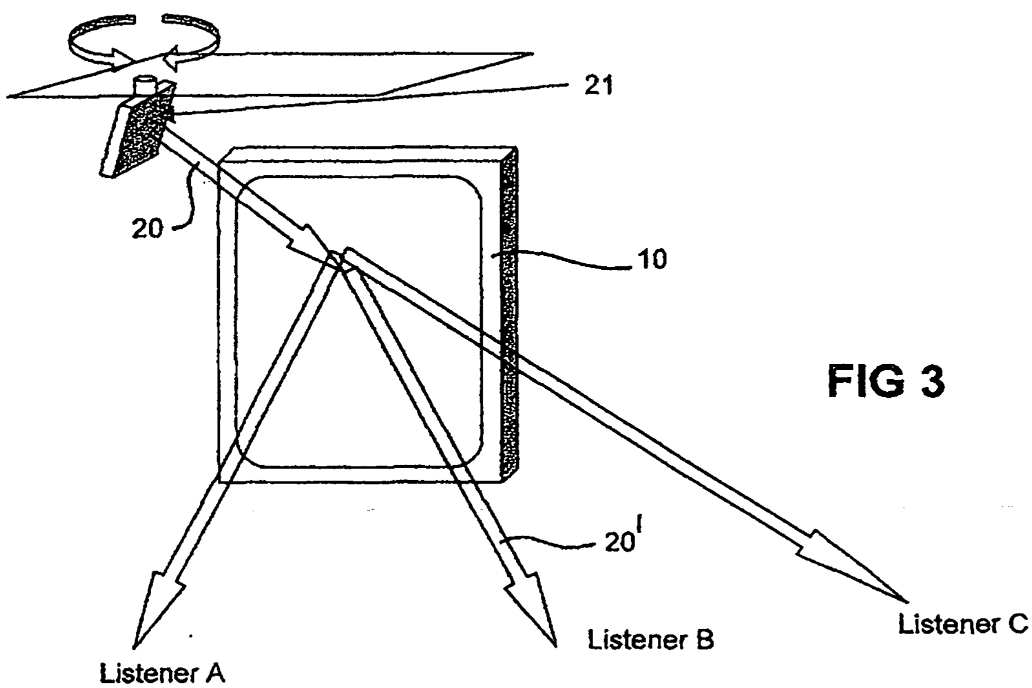
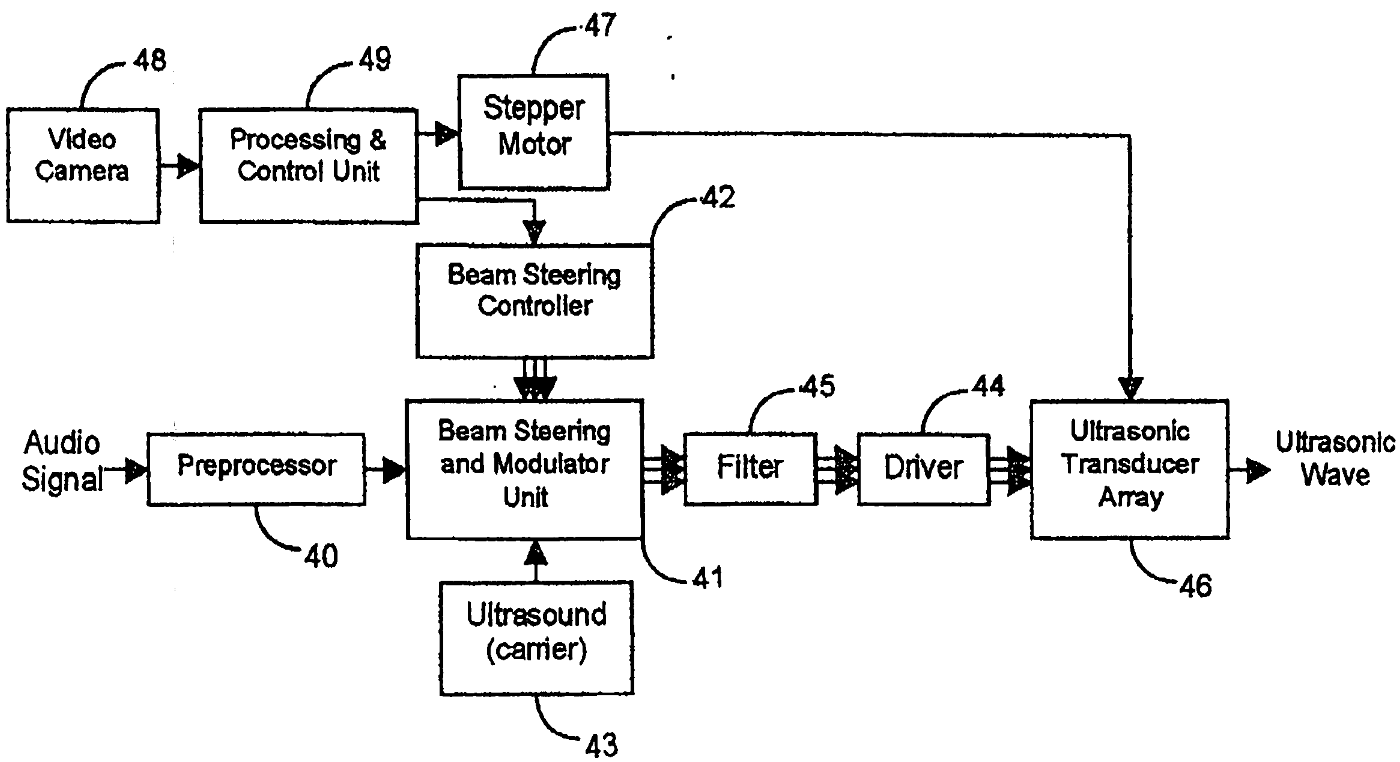

21
20
10
20'
Listener A
Listener B
Listener C

FIG 3



48
Video Camera
49
Processing & Control Unit
47
Stepper Motor
42
Beam Steering Controller
Audio Signal
Preprocessor
40
Beam Steering and Modulator Unit
41
Ultrasound (carrier)
43
45
Filter
44
Driver
Ultrasonic Transducer Array
46
Ultrasonic Wave


FIG 4

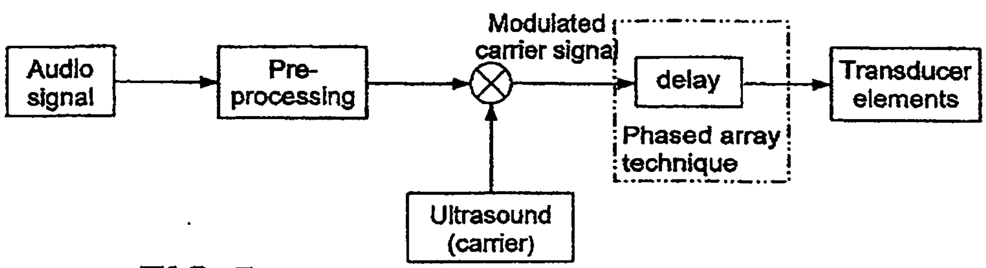



**FIG 5**
(PRIOR ART)

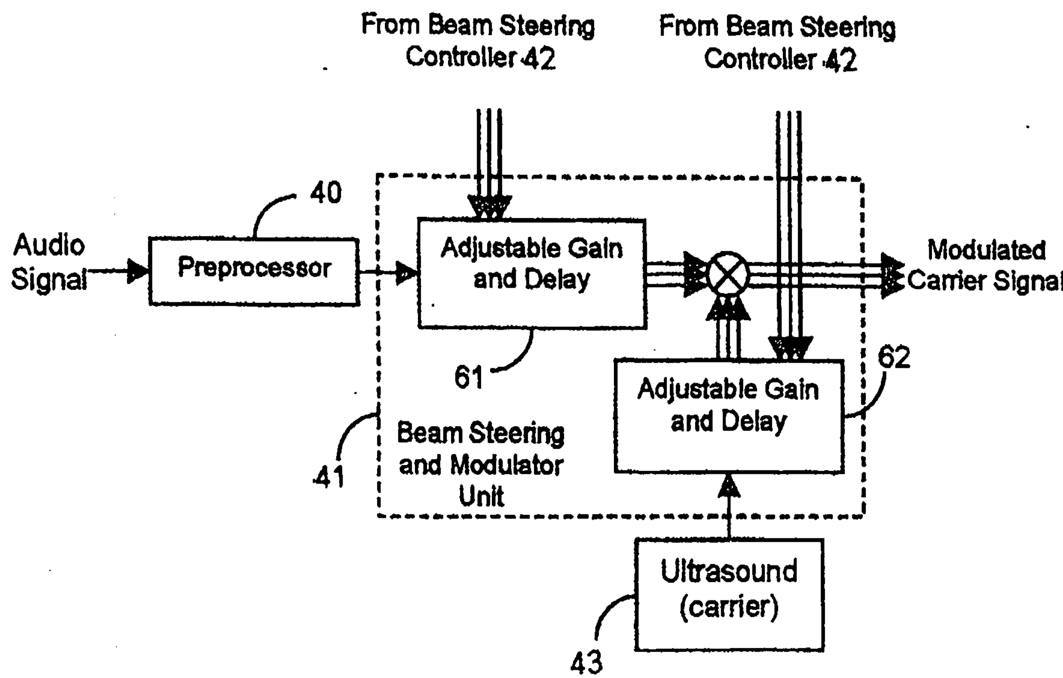

From Beam Steering
Controller 42
From Beam Steering
Controller 42
40
Audio
Signal
Preprocessor
Adjustable Gain
and Delay
Modulated
Carrier Signal
61
62
Adjustable Gain
and Delay
Beam Steering
and Modulator
Unit
41
Ultrasound
(carrier)
43

FIG 6

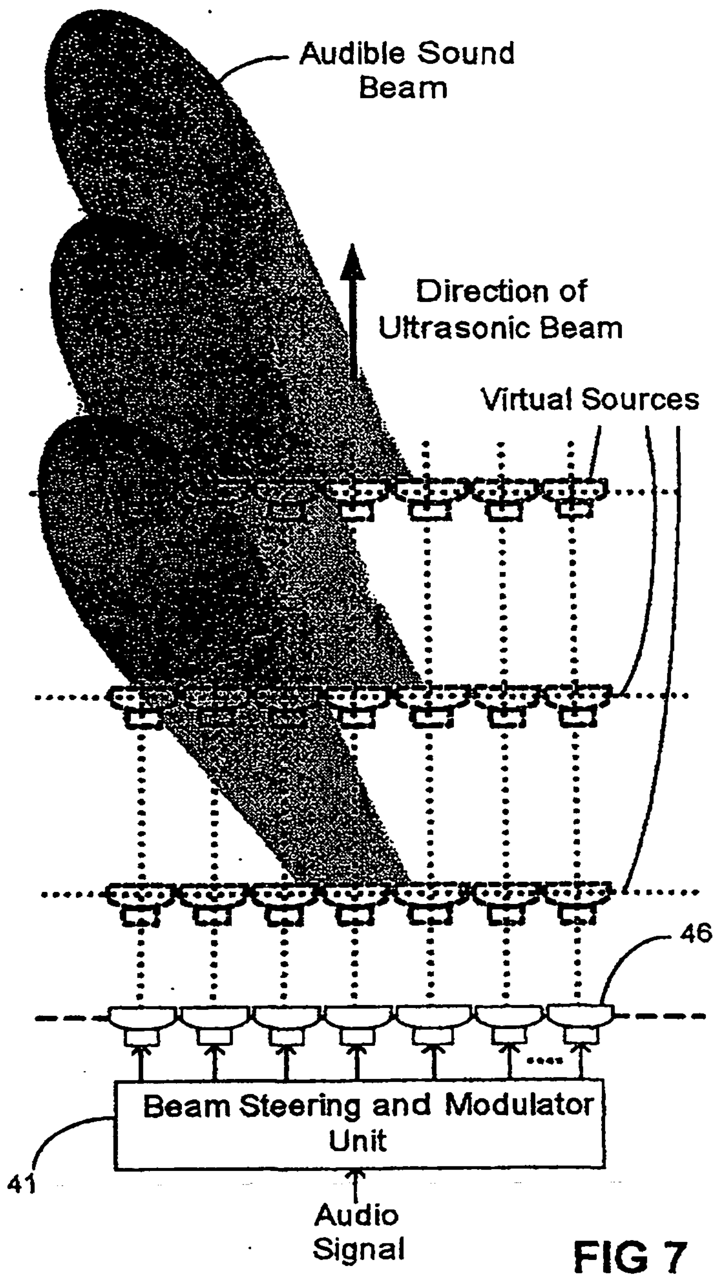

Audible Sound Beam
Direction of Ultrasonic Beam
Virtual Sources
46
Beam Steering and Modulator Unit
41
Audio Signal

FIG 7

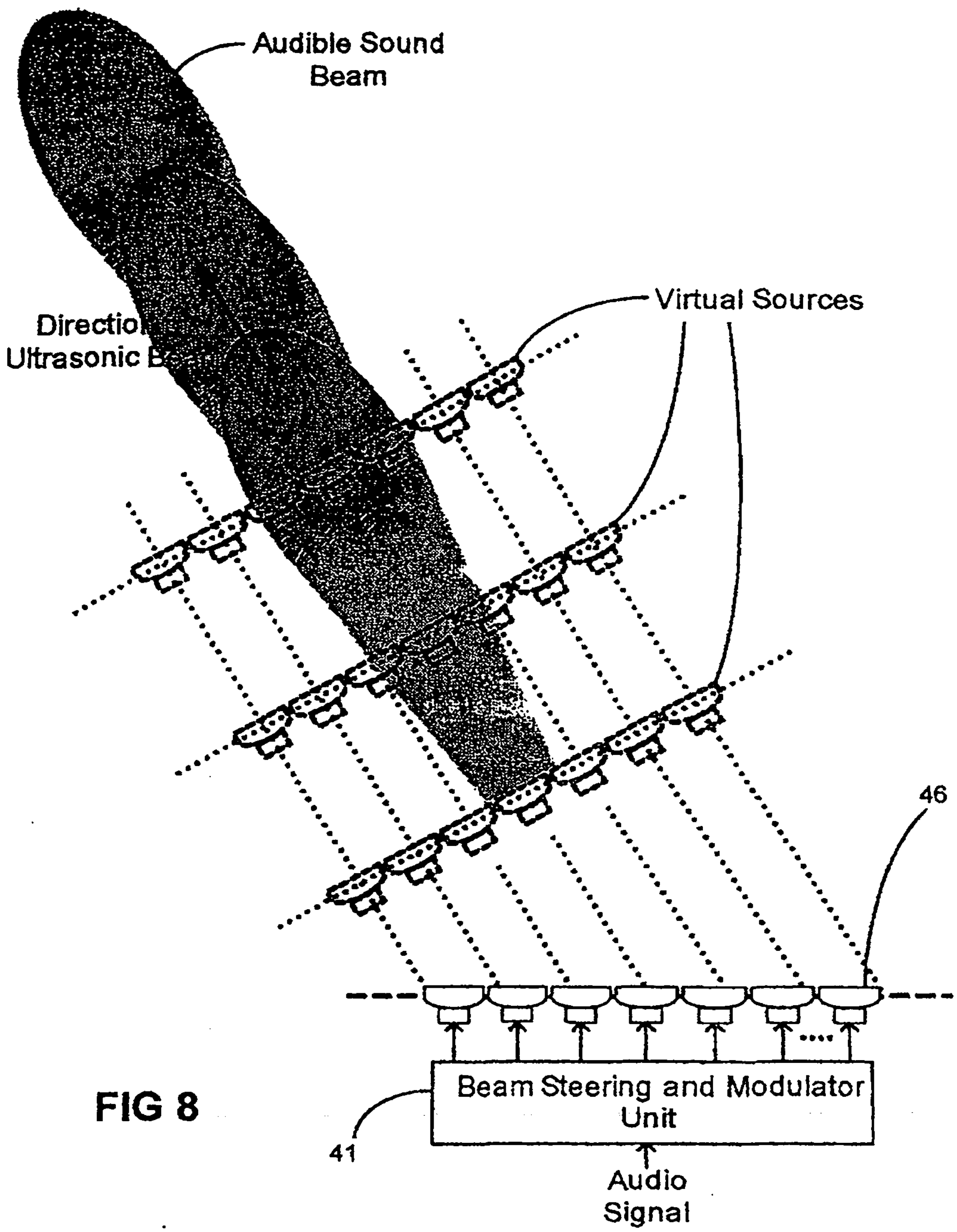

Audible Sound Beam
Virtual Sources
Directio
Ultrasonic B
46
Beam Steering and Modulator Unit
41
Audio Signal

FIG 8

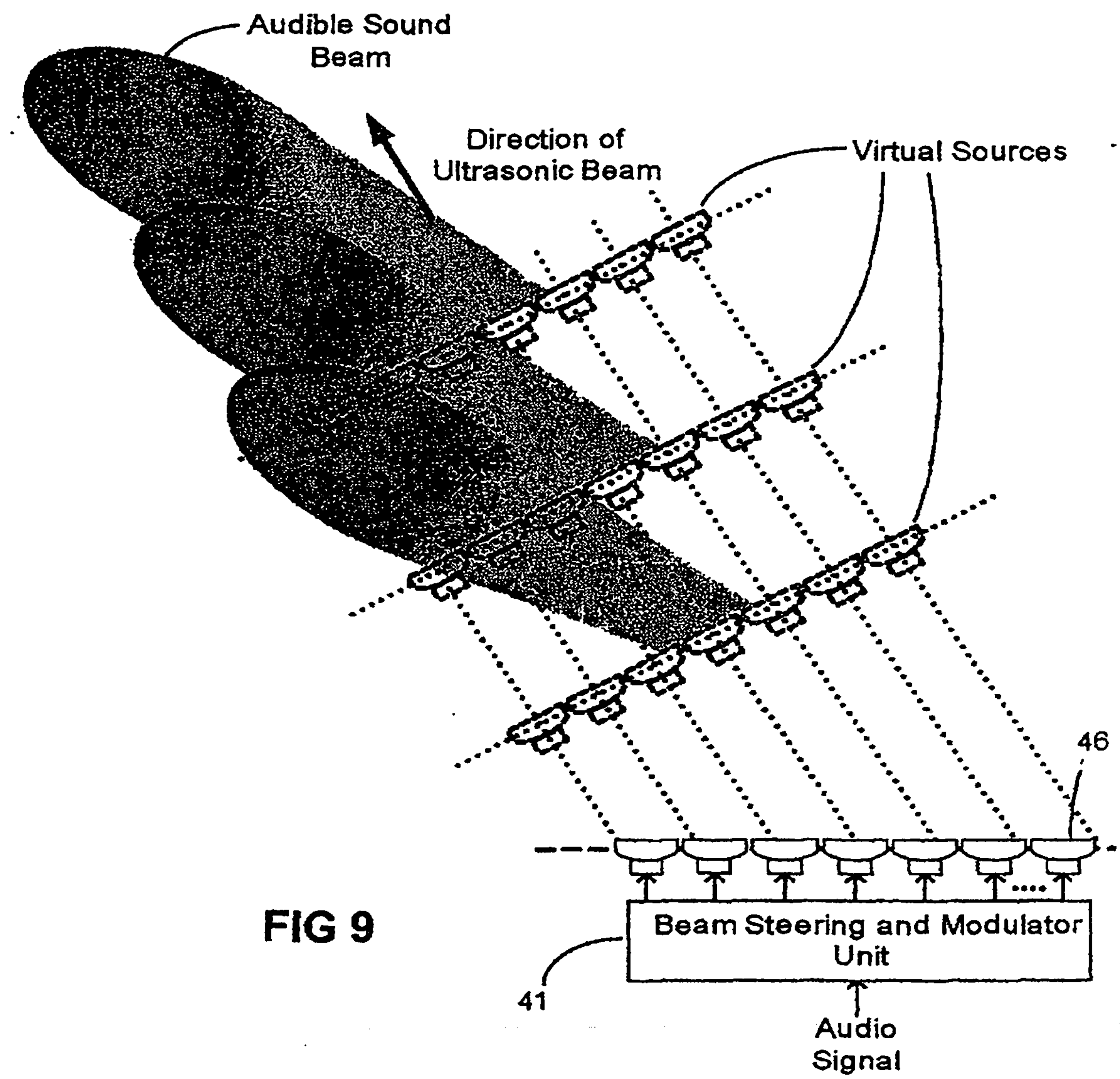

Audible Sound Beam
Direction of Ultrasonic Beam
Virtual Sources
46
Beam Steering and Modulator Unit
41
Audio Signal

FIG 9

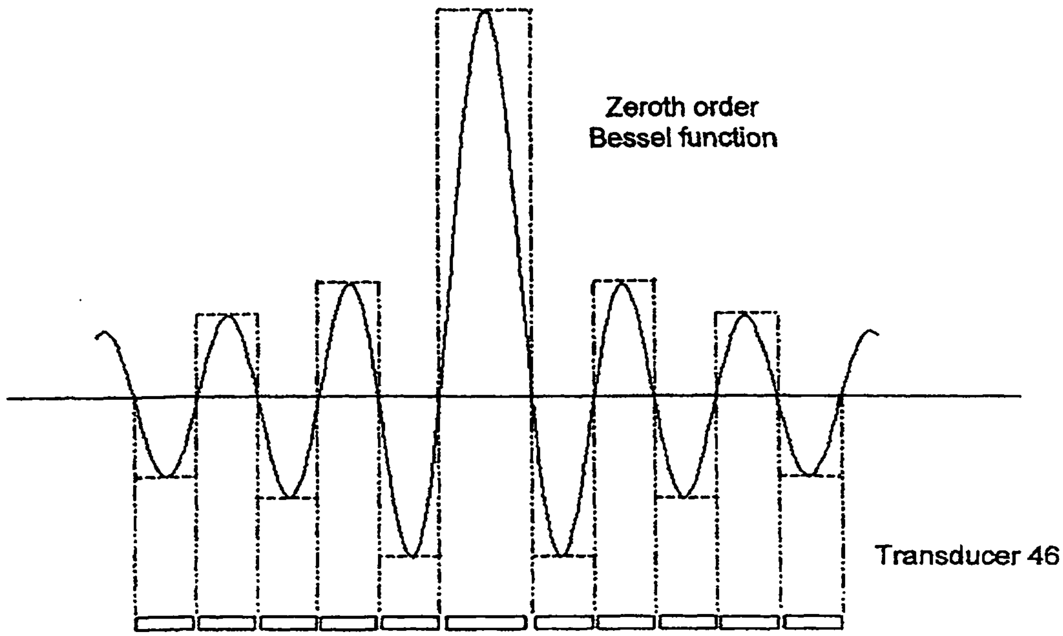



**FIG 10**

## ABSTRACT

## STEERING OF DIRECTIONAL SOUND BEAMS

Apparatus is disclosed for steering a directional audio beam (20) that is self-demodulated from an ultrasound carrier. The apparatus includes means for generating an audio signal and means (43) for generating an ultrasound carrier signal. The apparatus includes means for modulating the carrier signal with the audio signal and means (61, 62) for adjusting the amplitude and phase of at least one of the audio signal and/or the carrier signal to steer the audio beam to a desired direction. The apparatus also includes means (46) for generating an ultrasound beam in the said direction driven by the modulated carrier signal. The apparatus preferably includes means for weighting the audio and/or carrier signal by a zeroth order Bessel function to synthesize a Bessel distribution source. A corresponding method for steering a directional audio beam is also disclosed.

Figure 1 is to be published.